Contract Number

Nuvera Fuel Cells

Midpoint DOD/USCG PEMFC Installation Report

Proton Exchange Membrane (PEM) Fuel Cell Demonstration
Of Domestically Produced PEM Fuel Cells in Military Facilities

US Army Corps of Engineers
Engineer Research and Development Center
Construction Engineering Research Laboratory
Broad Agency Announcement CERL-BAA-FY02

USCG Aids to Navigation
Bristol, RI

June 2004

Executive Summary

Nuvera Fuel Cells has installed two Avanti™ fuel cell power systems (FCPS) at the maintenance facility of the Aids to Navigation Team, U.S. Coast Guard site located in Bristol, Rhode Island. Avanti™ is Nuvera's second-generation distributed generation fuel cell system, designed to provide approximately 3.5 kW each of baseload electricity and heat. It is a residential type Proton Exchange Membrane (PEM) fuel cell that uses Natural Gas as a fuel, operates in parallel with the grid and has cogeneration capabilities. This coastal installation site provides an opportunity to operate systems in a high salt air atmosphere with rapidly changing climatic conditions. With the cooperation of the USCG, this project serves as an excellent opportunity to evaluate fuel cell and system performance.

Inquiries may be made to

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Proposal – Proton Exchange Membrane (PEM) Fuel Cell Demonstration of Domestically Produced Residential PEM Fuel Cells in Military Facilities

1.0 Descriptive Title

DOD/USCG Avanti Fuel Cell System Demonstration: Bristol, RI

2.0 Name, Address and Related Company Information

Nuvera Fuel Cells, Inc
20 Acorn Park, Cambridge MA 02140
617.245.7500

DUNS Number	04-344-8021
CAGE Code	1YCK2
TIN	04-3403793

Nuvera was formed in April 2000 through the merger of Epyx Corporation, a wholly owned subsidiary of Arthur D. Little, Inc. and De Nora Fuel Cells, a wholly owned subsidiary of Gruppo De Nora of Milan, Italy. The merger brought together 10 years of fuel processor technology from Epyx and 10 years of fuel cell stack technology from De Nora, as well as a wealth of knowledge, know-how, and expertise in chemical reactor design, electrochemistry, and system integration. Nuvera has offices in Cambridge, MA and Milan, Italy and is a privately held company with investors including Amerada Hess Petroleum, de Nora SpA and Renault.

3.0 Production Capability of the Manufacturer

Nuvera is committed to developing commercially viable products utilizing it's fuel processing capabilities in addition to straight hydrogen fuel cell systems for transportation and distributed generation applications.

Currently, field trials are being conducted on three continents with various corporate partners to evaluate systems in a variety of markets. The company is poised to take advantage of any emerging opportunities with a small on-site production facility capable of assembling less than 1000 units per year in the near future. Nuvera has the intention of creating a larger manufacturing capability when it becomes prudent to do so for mass production of our distributed generation hydrogen and fuel processing PEMFC systems as well as hydrogen generation stations. It is the intention to continue supplying the automotive market with fuel cells, while licensing out the rights to manufacture fuel processing sub-systems for various transportation applications.

For more information, please contact Robert Derby at 617.245.7500
or visit www.nuvera.com

4.0 Principal Investigator(s)

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6.0 Past Relevant Performance Information

Avanti™ Fuel Cell System Installation – 1 unit (Japan Gas Association – Fuel Cell Challenge)
Installation of an Avanti Power Module at JGA/JIA fuel cell competition with Takagi Cogeneration Unit integration in December 2003

Maintenance Partners: Takagi Industrial Co,. Ltd
R&D Department,
201 Nishikashiwabara-shinden,
Fuji-Shi, Shizuoka-Ken,
417-8505, Japan

Hiroshi Ichikawa
+81-0545-33-0869

Primary Contract: Mitsui & Co. Ltd.

2-1 Ohtemachi 1 Chome
Chiyoda-Ku, Tokyo

Kazuhiro Nagoya
81-3-3285-4699

Primary Testing: Japanese Gas Appliance Institute
4-1-10 Azusawa
Itabashi-Ku, Tokyo

Miura Motoki
03-3967-4252

Avanti™ Fuel Cell System Installation – 2 units installed for New Energy Foundation (NEF) at Sinanen and Kandenko)

Primary Contract: KURITA WATER INDUSTRIES LTD.
4-7, Nishi-Shinjuku 3 Chome,
Shinjuku-ku, Tokyo

Project Manager: Shigeaki Satoh
81-3-3347-3338

Site Address: Sinanen
39-19 Higashi Shinagawa 1-Chome
Shinagawa-Ku Tokyo
140-0002 Japan

Site Manager: Hiroyuki Ikeda
03-3471-0531

Installed Avanti™ Power Module on roof of Sinanean CNG automotive refueling station, providing electricity and hot water for car wash facility. Fuel cell testing project with Japanese New Energy Foundation with Kurita Water Industries.

Site Address: Kandenko
1-4-16 Kandenko
Tokiwa-Cho 1 Chome
Urawa-Ku, Saitama-shi, Tokyo

Site Manager: Tetsuo Motohashi
048-834-7411

Installed Avanti Power Module outside of large dormitory, providing electricity and hot water under guise of Japanese New Energy Foundation with Kurita Water Industries.

Caterpillar
Spring 2003
Installed Model B ethanol reforming fuel cell system at Aventine site in Pekin, IL

MIT Lincoln Laboratories
Summer 2002
Installed two H2PM Hydrogen Power Modules

Verizon
August 2002
Installed Nuvera PowerStream 5kW Unit at distribution station in Woburn, MA

RWE
Andreas Feldman
October 2002
Installed Nuvera PowerStream Unit at Mechernich Park, Germany

7.0 Host Facility Information

The U.S. Coast Guard, Aids to Navigation Team is located in Bristol, Rhode Island on a peninsula located between the Narragansett and Mount Hope Bays. Bristol is about 12 miles southeast of Providence and 12 miles north of Newport. This site maintains waterway navigation equipment and support of the heavily traveled waterways. The interior of a maintenance building used to repair equipment and fabricate metal and wooden parts for ships is the location of the installed Avanti™ units. Additionally, it houses an electronics repair facility and offices. The facility is staffed 24 hours per day, 7 days per week with a night watch-person, but has primary operation hours of 7am to 3:30pm.

The primary source of heating has been a gas fired forced hot water system located within the maintenance building mechanical room. Several overhead radiator heating units with fans are located throughout the building and an electric water heater provides additional hot water.

Natural Gas to the facility is provided by New England Gas (http://www.negasco.com). Electricity is provided by Narragansett Electric (http://www.nationalgridus.com/narragansett).

8.0 <u>Fuel Cell Installation</u>

Within the maintenance building, the section that houses the FCPS has an area of 938 sq ft and the layout is detailed in Figure 1. The Avanti™ units are placed along the north wall of the maintenance bay just outside the mechanical room due to the proximity of available utilities.

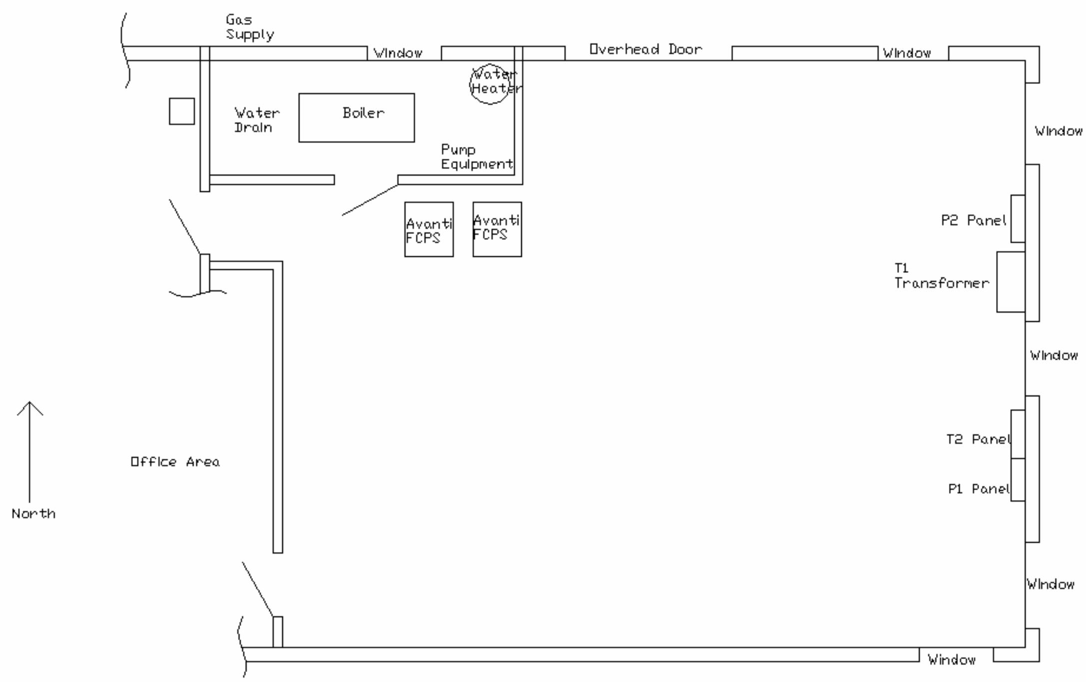

Figure 1: Maintenance Shop Layout

Once this decision where to install the systems was made and how the utilities would be routed, the first steps of the physical installation were to bring the electrical tie-ins from the distribution panel P2 to the designated area by a licensed electrician. Auxiliary 110V power was then routed outside for the exhaust duct and radiator fans.

Licensed plumbers then tapped off the facility boiler gas supply, installed designated meters, extended lines around the mechanical room, through the wall and terminated at the appropriate site

Figure 2 : Installed Gas Meters

Still before the fuel cell systems arrived, the exhaust ducts were routed through the mechanical room and through a portion of a pre-existing window where the vent fans were installed.

The Reverse Osmosis water filtration system was mounted in the mechanical room, and the existing city water supply and drain lines were tapped into and routed through the wall to the future system location.

A small area of ground was leveled on the North side of the building, and bricks were laid down to form the bases that the heat rejection boxes would sit upon. CPVC tubing was run from these cogeneration box pads through the exterior wall of the maintenance shop, up to the ceiling and then over the length of the room and down to the Avanti™ units.

The site data acquisition system and data collection computer were then mounted on the near wall along with a small supply cabinet. One of the final steps taken before the actual fuel cell systems were installed was the routing of the cable internet line to enable communication.

Figure 3: Cogen Boxes and Exhaust Fans

The fire department and electric company were notified of the intentions to operate and connect to the grid, and all basic requirements were satisfied (although no specific permits were needed).

The overall effort to prepare the facilities for the installation of the fuel cell power systems spanned ten working days. This included eight hours of labor from a licensed plumber, 16 hours of a licensed electrician and the better part of two weeks time of two engineers designing the layout, purchasing materials and physically setting up the equipment to provide the necessary site utilities and data acquisition systems.

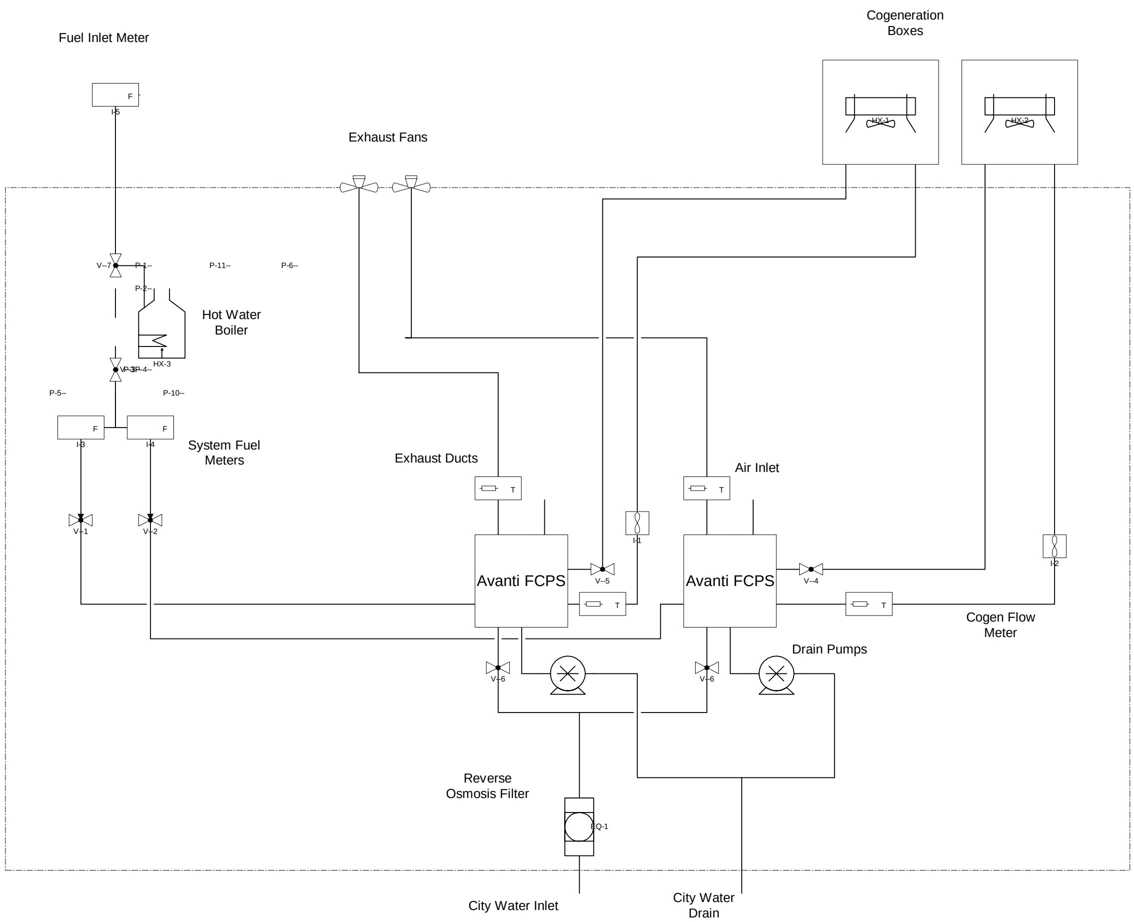

Figure 4: System Interface Schematic

The first of the Avanti™ units was installed November 11th, 2003. Once the system was thoroughly inspected, power was fed to the inverter and the various pumps, blowers, solenoid valves, etc. were actuated to ensure functionality. The cogeneration lines were filled with fluid, leaks resolved and pumps primed. On November 13th, the first operational testing ensued.

Figure 5: Crated System

Figure 6: Positioning

Figure 7: Mating with Utilities

Figure 8: Installed Units

The following Table contains historical data of the electrical loads of the maintenance building at the Aids to Navigation Coast Guard facility for the year 2002. From this it can be seen that two Avanti fuel cell power modules operating nominally at 3.5kW would not be able to fully supplant the grid in this situation, particularly in the winter months as the demand is too high. However, during off-peak and summer operation it is more than likely that there will be many instances of excess capacity.

Bill Date	kWh Use	Net Bill	Avg. Cost/kWh	# of day	Avg. Use/ Day
3/29/2002	8000	$738.99	$0.09	28	285.7
4/29/2002	7800	$729.27	$0.09	31	251.6
5/30/2002	8100	$750.57	$0.09	32	253.1
6/28/2002	7100	$679.52	$0.10	28	253.6
7/29/2002	3600	$430.84	$0.12	30	120
8/26/2002	5800	$565.61	$0.10	29	200
9/25/2002	4600	$480.34	$0.10	32	143.8
10/25/2002	5800	$565.61	$0.10	28	207.1
11/25/2002	7300	$672.20	$0.09	30	243.3
12/31/2002	9700	$850.79	$0.09	36	269.4
1/29/2003	12100	$1,042.47	$0.09	31	390.3
2/27/2003	11600	$1,012.21	$0.09	29	400

Table 1. Site electric billing information.

Gas usage for the site is increasing as the space heating will still be needed in the colder months, and additional natural gas supply is required for the operation of the fuel cell power system. At full power, the FCPS operates at approximately 12kW thermal input or

43 scfh. At this rate and with the current utility costs, an economic detriment is expected – although an alteration in setup to utilize cogeneration capabilities might swing the pendulum in the other direction if the initial system costs and higher than expected upkeep are overlooked.

9.0 Electrical System

Inside of the maintenance shop there are two transformers, T1 and T2 and two distribution panels marked as P1 and P2 as seen again in Figure 1. T1 is a 3 phase, 225 KVA transformer with a 480V / 270A high-voltage side and 208V with four 120V taps rated at 625A total which feeds the P2 distribution panel with a 225A main breaker switch. T2 is a transformer that feeds P1 and a second subpanel that is incorporated into T2. This subpanel is rated at 440V and 600A, it contains 5 breakers, one connected to a welder and the other 4 supplying power to the ship power supplies located on the dock. The primary dock supply is connected to a power transformer that is used to supply power to ships at dock. The headquarters building that is located on site is supplied by a second electrical service with a stand-alone meter.

The Avanti™ Fuel Cell Power Module is designed to operate as a grid parallel system. It is dependent upon the electricity regularly fed into the facility to power it during startup, standby and shutdown modes, typically consuming 250-500W of power that has been converted to DC current by the integrated power inverter during such operation. The system is not capable of providing backup power in the event of a grid failure as a result.

When generating, the fuel cell creates electricity on an 80V DC internal bus that first provides power for the auxiliary components. The remainder is then fed to the same inverter which then feeds 208V AC back to the electrical grid. The output is generally between 10 and 20A on two phases (AB on Alpha 1 and BC on Alpha 3), capable of feeding 2-4 kW to the facility. Whatever is not consumed by the wood-shop, machine-shop, maintenance garage, building offices or external boat utilities during off-peak hours are sent back to the power grid. On-site net-metering effectively spins the kWh meter readings backward, thus increasing potential electric bill savings.

Physically, new circuit breakers were installed in the existing 117/208 VAC distribution panel (P2) on each phase as depicted in Figure 9. From there, lines were run up along the ceiling across the shop into the system vicinity where they terminate in a fused disconnect for each system. Power can be shut off and locked out independently for service work. From there the lines pass through the electronic power meters that monitor the voltage, current, frequency and harmonics of the electricity being generated by or fed to the inverter. The meters will also calculate power output, power factor and total energy produced, and will open a contactor to disconnect the fuel cell system from the grid when an alarm is triggered by out of range voltage or frequency as required by the Narragansett Electric Power Generation Interconnect guidelines. This safety measure is replicated in the inverter software, and either cutout will occur regardless of whether the fault is on the fuel cell or an electric grid anomaly.

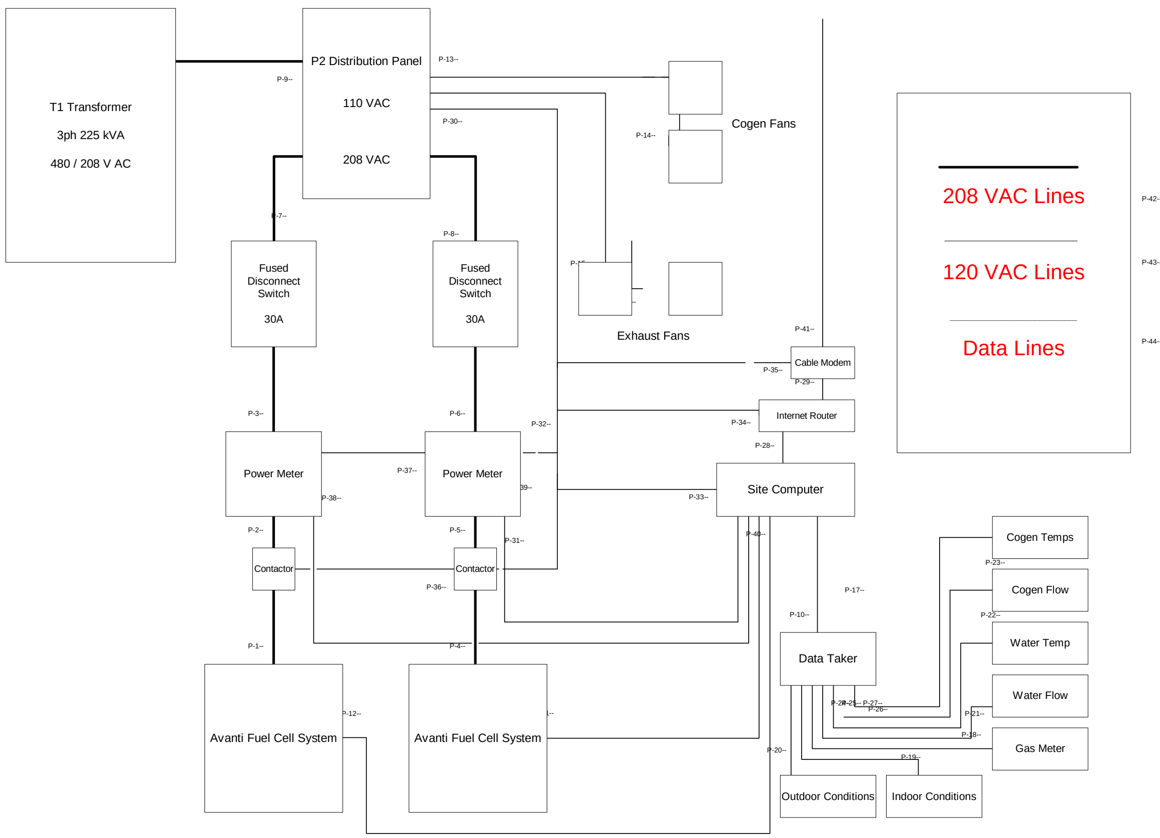

Figure 9: Electrical System Diagram

10.0 Thermal Recovery System

The heating system for the maintenance building is located in the mechanical room and is described as forced hot water. The system uses a natural gas fired boiler connected to a city supply outside of the north wall.

The current setup for heat dissipation from the FCPS is a radiator system installed outside the north face of the maintenance building and is independent of the forced hot water system. These Cogen Boxes are placed at ground level, and consist of a typical automotive style radiator with fans pulling air through a perforated sheet metal cabinet which are actuated by a temperature switch. The Cogen fluid is a mix of water and propylene glycol, and runs through CPVC piping 10 feet in the air along the ceiling from the Avanti systems before exiting through the wall and falling down to the Cogen boxes. Here, the accumulated heat gathered from the cuel cell system is rejected to the atmosphere before returning significantly cooler to the systems. Ideally, the radiators would be placed on an elevated frame or the roof of the building at a height that would aid in the bleeding of air from the lines of the closed system. This would aid filling and topping off the fluid level – but the current setup is functional once filled if not completely user-friendly.

Figure 10: Cogeneration Boxes

There is potential to install a radiator system inside of the building for supplemental heating of the maintenance bay. Since each room in the building has its own heat exchanger and control system for the forced hot water system, it may be possible to install a radiator in parallel without affecting the current heating system. The heat dissipation from the FCPS is rated at 5kW for each unit, and would be quite effective at heating the large maintenance area. This would be welcomed next winter as the space can be quite cold with the slab concrete floors and frequently wide-open overhead door. A simple control scheme could be used to switch over to the current outdoor radiators when heat is not required.

The current setup is not instrumented to monitor the rejected heat at the radiator, but at the Avanti interfaces, a typical measured state is 65C outlet temperature with a 30C return at a flowrate of 2.3 lpm. The mixture of glycol and water can be varied seasonally, but using an approximate 50/50 mix heat capacity of 3.4 kJ/kg*K yields 4.6 kW of heat available.

11.0 Data Acquisition System

The Avanti Fuel Cell Power System contains a series of six embedded control modules centered around an ECU that serves as the brains of the system. It operates on a CAN protocol bus to communicate with the Burner Management Module and the Inverter; and external computers can tap into this feed to view the system performance via a dedicated LabView window and archive the CAN bus data that the system uses to run itself on the dedicated site PC. Recorded parameters include various fuel processor and fuel cell temperatures, digital input and output control signals for the balance of plant components and electrical output as reported by the inverter.

To measure the environmental conditions at the Coast Guard site, a DataTaker system has been installed to monitor and store a number of parameters and calculate certain values including:

Natural Gas Volume – as measured by typical gas meters with a digital output
City Water Inlet temperature
City Water Inlet flow
Water Drain volume

Cogen Fluid Inlet/Outlet temperature
Cogen Fluid flow
Exhaust Temperature
Outdoor Temperature
Outdoor Relative Humidity
Ambient Pressure
Indoor Temperature
Indoor Relative Humidity

This data is stored locally in the DataTaker hard drive, and then is unloaded daily to the site PC.

Finally, Power Meters measure and calculate the electricity either consumed or delivered by the fuel cell systems to the grid. They do not have any data storage capacity, but communicate continuously via RS485/232 to the site computer, where the individual phase voltage and current are displayed as well as the frequency and power output of each system on another LabView window. This information is then also logged on the PC.

A cable modem has been installed at the site to connect the site computer to the internet through a router. The PC can then be accessed and viewed remotely, and Nuvera also downloads the necessary data off of that machine and archives daily on a server in Cambridge.

A change from the initial data collection plan has been a switch from one site computer to two. With all the applications being run, the remote accessing of the one computer was overloading it regularly.

Figure 11: Nearing completion of DAQ

12.0 Fuel Supply System

The Natural Gas supply that feeds the boiler in the mechanical room was tapped off of and split into two trunks with a main shutoff valve for the two systems. Designated volumetric gas meters with digital outputs were mounted to the wall inside the mechanical room, and one inch pipes were run up around the door frame and down and out through the interior wall where manual shutoff valves are located for each individual system. Stainless flex-lines are then run from the wall taps to the back of the fuel cell systems, with yet another manual shutoff valve at the fuel inlet port.

When an internal solenoid valve is opened, the fuel then passes through two desulfurizer canisters before reaching the compressor that delivers the fuel to the reformer. This system is robust enough to handle changes in line pressure, although variations in thermal heating value due to extreme environmental conditions and heavy area demand can create issues.

13.0 Installation Costs

The majority of the incurred charges associated with the installation of the two Avanti fuel cell power modules at the Coast Guard site in Bristol, RI involve labor and associated personnel costs. In future occasions, engineers will be able to design the layout, purchasing departments will be able to supply all the required materials and technicians trained in system installation will be able to perform the required work in a much more cost and time-effective manner than this iteration. Ideally, laborers would also be licensed to perform the electrical and natural gas services in the municipality that the systems are being installed at, further reducing the labor charges billed to outside contractors.

The basic materials required to interconnect the fuel cell systems to the utilities were quite simple and fairly inexpensive. The data collection systems significantly boosted the as-installed cost. When the fuel cell power modules eventually mature as product and such intensive monitoring becomes superfluous, the capital investment in PC's, data acquisition devices and required components such as flowmeters become dispensable – and thus eliminating a large percentage of the installation costs.

The following is a rough breakdown of the related costs incurred:

Nuvera Engineers Based on two full weeks of labor performed	
160 hrs at $100/hr	$16,000
Miles and expenses	$1,800
Licensed Plumber Services – labor and materials	
2 plumbers x 4hrs	$825
Licensed Electrician Services	
16 hrs at $75/hr	$1200
Cable internet installation	
Service Fee	$80
Shipping	
Crates (2 avanti, 2 inverter)	$900
Shipper (2 trips)	$850
General Installation Materials	$1200
See below for full list	
Data Acquisition Components	$8500
See below for full list	
Total	**$31,355**

The following is a detailed list of all the materials and components used:

Plumbing Materials

Natural Gas – connecting systems to supply taps
- Stainless steel flex tubing
- compression fittings
- shutoff ball valve

Cogen – connecting systems to heat rejection boxes
- CPVC Tubing – ¾" x 8' lengths
- CPVC Fittings – unions, 90's, 45's
- CPVC Shutoff Valves – ball valves
- Bleeder valves – with float at line high-point

CPVC Cement – “orange and purple”
Silicone Rubber hose – connecting CPVC to radiator boxes
Nylon Fittings – hose barb
Propylene Glycol – industrial grade
Radiator box landscaping bricks

Water/drain – connecting systems to city water supply and drain
Copper Pipe Piercing Tap – “refrigerator icemaker” valve
Teflon tubing – ¼”
Compression fittings – unions, Tee’s
Reverse Osmosis Filter system – undersink residential style
CPVC Tubing – ½” x 10’ lengths
CPVC Fittings – unions, 90’s, Tee’s
CPVC Shutoff Valves
Condensate Pumps – transports ground level water to drain

Exhaust – venting exhaust gases from systems outside
Exhaust fans – 120V AC
Ducting – 6” diameter sheet metal lengths and unions
Hardware – sheet metal screws
Plywood sheet – covering top portion of window holding fans
Caulk – to seal exhaust fans and plywood seam

Electrical – to tie systems into grid

Components
Circuit Breakers
Fused Disconnects
Contactors
General Supplies
Wire
Cable
Connectors
Conduit
Hangers
Junction boxes

Data Acquisition – additional equipment not required for system operation

System Data – monitoring system performance
Site Computers – HP PC’s
CAN cables – connecting Avanti systems to site computers
Uninterruptable Power Supply – to keep site computers operational

Electrical – measuring output power
Power meters – with output signal
Current Probes – donut transducers
Signal Converter – RS232/485

Site Data – measuring environmental conditions
Data Taker – DT800

Pressure transducer - atmospheric
Humidity Sensors – indoor/outdoor
Temperature sensors – indoor/outdoor
Cogen flow meters – turbine style
Cogen flow meter flexible clear tubing / fittings
Water flow meters – paddle style
Water flow meter compression fittings
Cogen/water/exhaust Thermistors
Thermistor compression fittings
Wire – hookup wire
Cable – shielded multi-pair
Connectors – butt-splices, ferrules, crimp pins
Conduit – protects wire-runs

Communication -
Cable Internet Service
Internet Router

Miscellaneous Supplies
Supply Cabinet
CO / Smoke Detector
Combustible Gas Detector
Desk/Table
Chair

14.0 Acceptance Test

The site preparation work was completed by early November 2003, and the first fuel cell system installed on November 11th. This system was then operated to ensure that the facilities were functional and the data acquisition worked. There was a delay on the shipment of the second unit until the end of the year, and it was installed and first run on January 5th, 2004.

The next phase of operation involved running the systems manually to determine the proper set-points following the on-site fuel calibrations. The Heat Cogeneration System (actually heat rejection in this application) also had to be fine-tuned with the proper flow restriction. Making this particularly difficult was the brutally cold January weather this year in New England. With temperatures regularly below zero F for a two week period coupled with the biting wind coming off the bay at the Coast Guard facility, the return temperatures from the radiator boxes located outside the building were much lower than anything these systems had ever experienced. Compounding the problems were the fact that this generation of Avanti fuel cell system was designed for indoor operation (although others have been retrofitted for outdoor use), and in the Maintenance Building – the overhead door regularly had to be left open for the majority of the day. Without proper insulation for this cold of an environment, this would significantly chill the steam loop and prevent optimal fuel processing. Also, during the most severe periods we had a few drastic pressure drops in the natural gas supply due to the overtaxed heating requirements in the area that caused some problems. These conditions made it difficult to commission the systems, but at least one weather extreme was experienced in the early stages of operation rather than further along in the performance period.

Once all of these issues were resolved, new software with the proper set-points was loaded onto the ECU control module. The automated systems were then allowed to run for the next couple of weeks to resolve any infant mortality issues with any of the components. Once everybody was satisfied with the operation, it was decided to begin the performance period mid-February for both installed systems.

Attached in the Appendix is the documentation of a portion of the Acceptance Test. A file has been created merging the system data with environmental data for each system while deleting proprietary information.